Brighter / fatter effect in DECam

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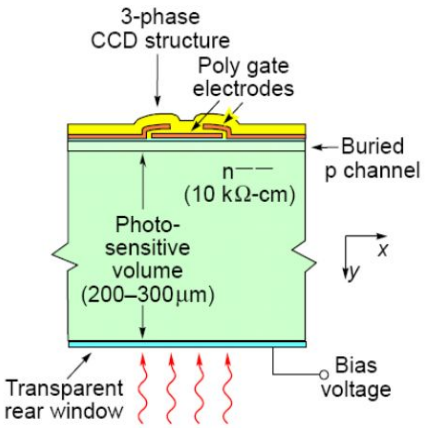
Agenda

- DECam and DES
  - status update
  - brighter/fatter phenomenology
- Charge deflection model
  - Introduction
  - DECam measurement and model
  - Effects on galaxy shape measurement / Weak Lensing
  - Correction
- Summary

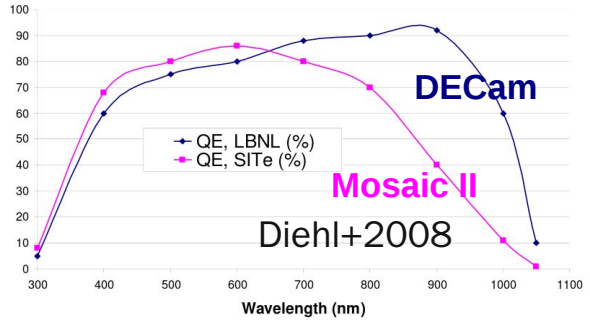
The Dark Energy Camera:

Overview

- 62 science CCDs, LBNL, 2k x 4k, 250μm thick
- good QE over wide wavelength range
- 3 sq. deg. FOV
- at prime focus of Blanco 4m / CTIO

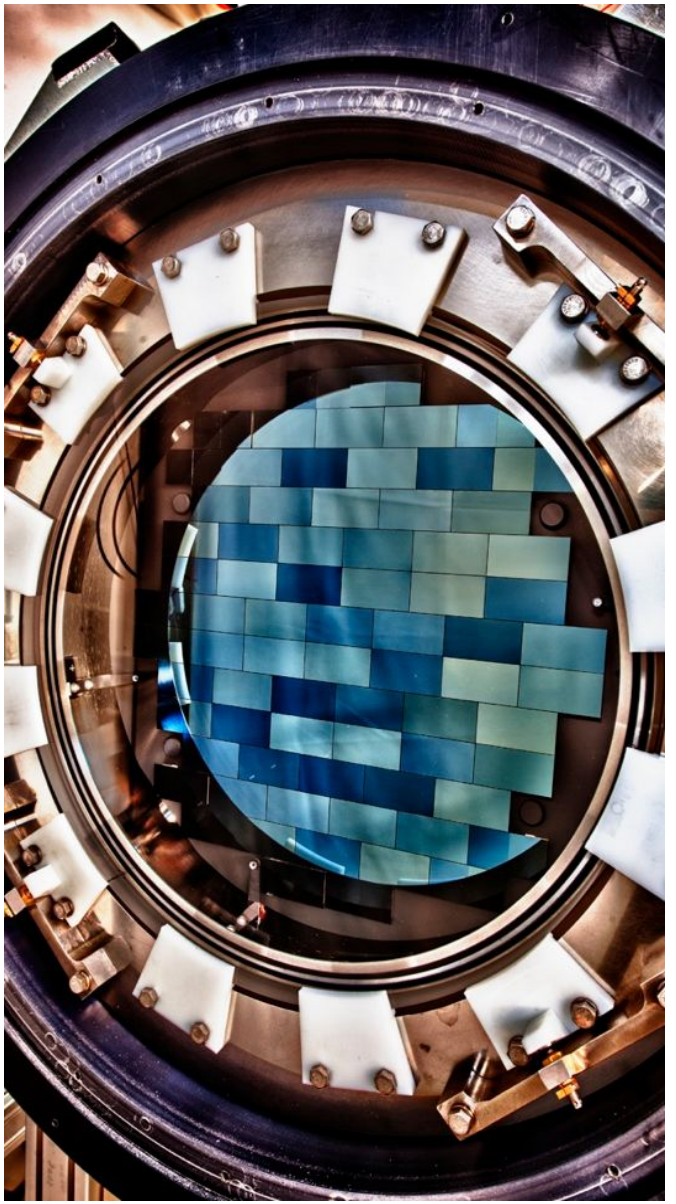


Estrada+2011



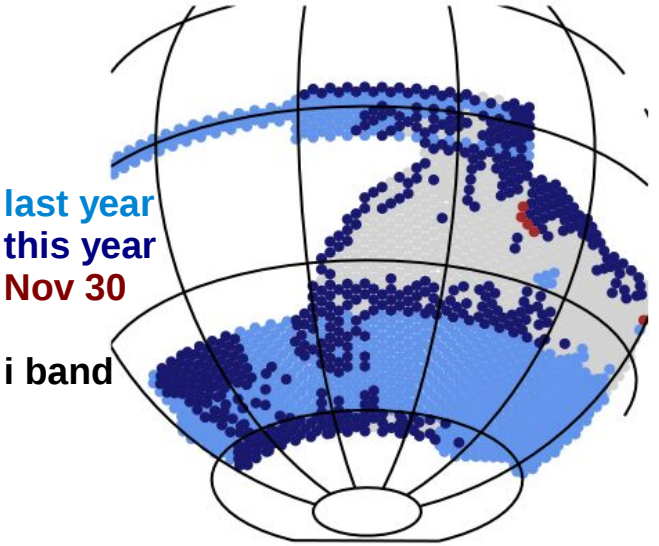
Diehl+2008

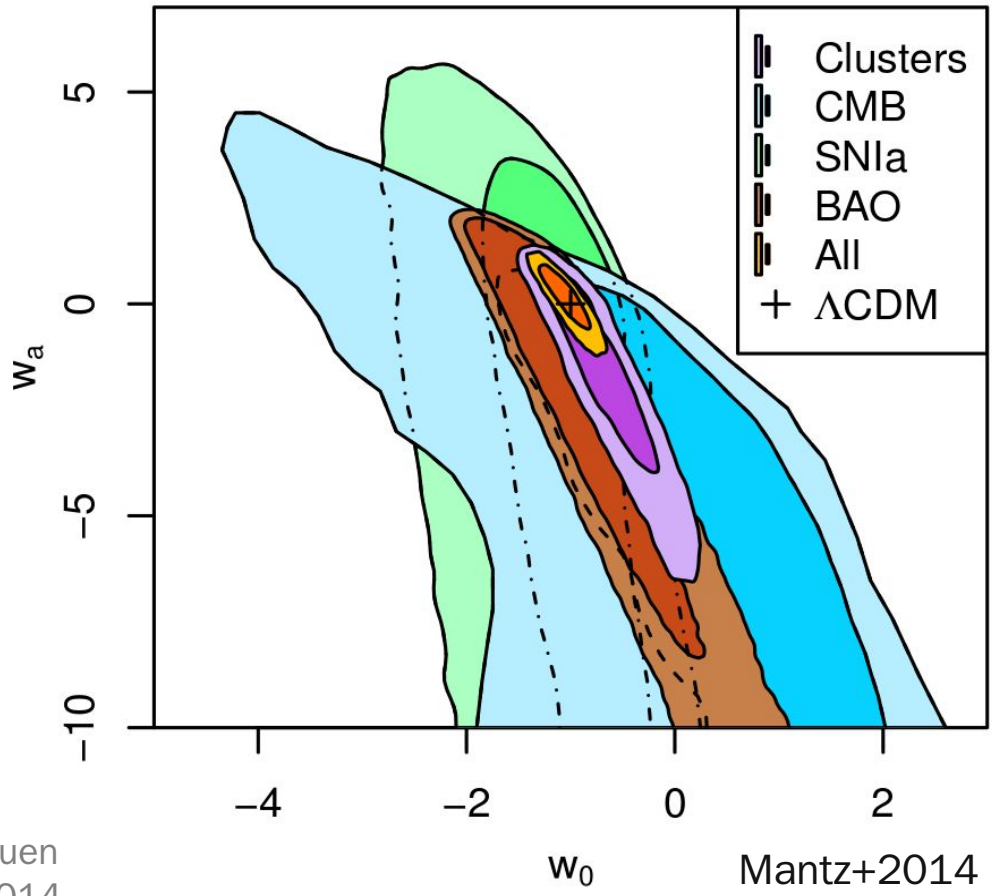
T. Abbott & CTIO/NOAO/AURA/NSF



The Dark Energy Survey

- 5000 sq. deg. survey in grizY, 5 years, ~300 scientists, 28 institutions
- Primary goal: dark energy eqn. of state
- Probes:
  - Clusters of galaxies
  - Galaxy 2-point / BAO
  - Supernovae
  - Weak lensing
- First science results out, more to come soon!





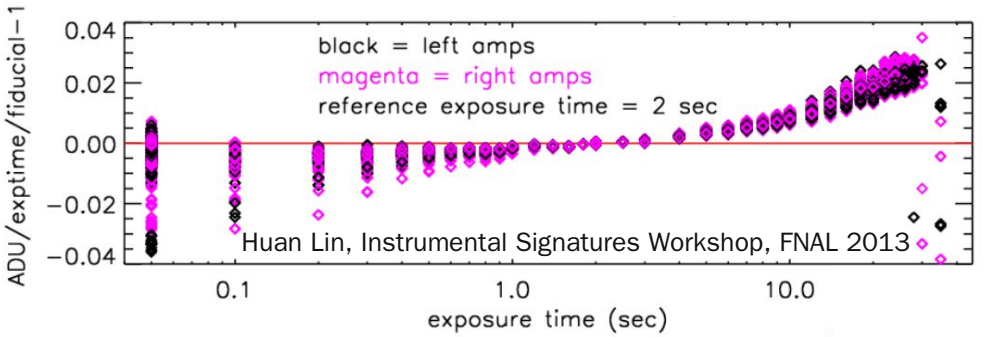
Mantz+2014

The Dark Energy Camera:

Precision astronomy relevant CCD/Amp effects

- Flat field non-linearity

  amplifiers few % nonlinear over the non-saturated dynamic range

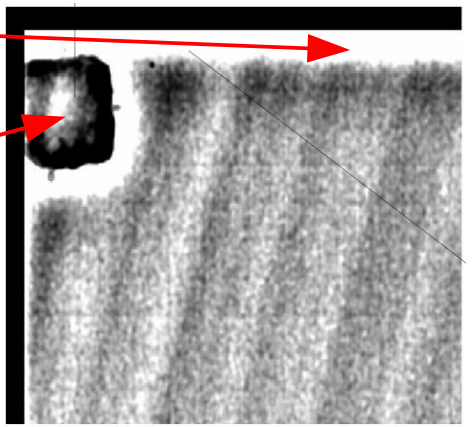


- Glowing edges

  increase in effective pixel area at border

- Tape bumps

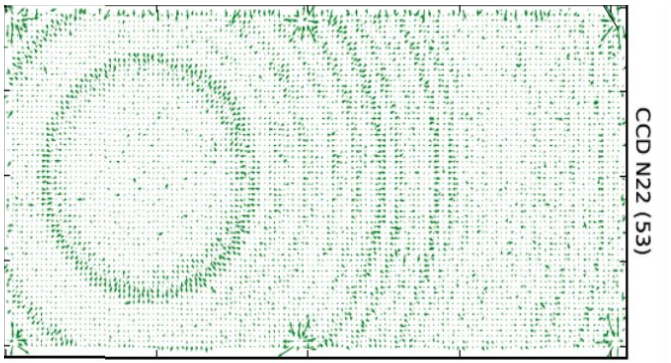
  physical deformation at position of double-sided tape distorts electric fields



Andres Plazas+2014,
shown at PACCD 2013

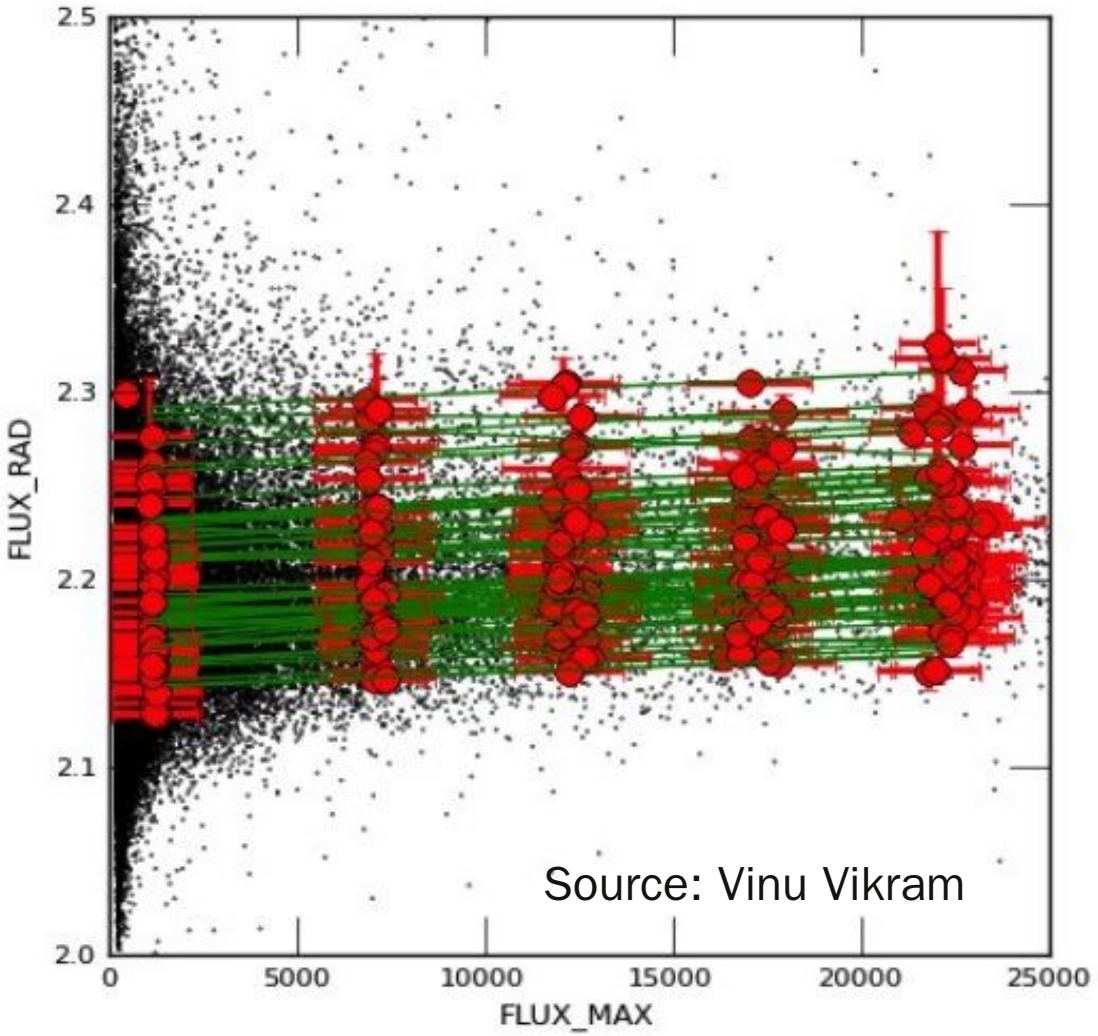
- Tree rings

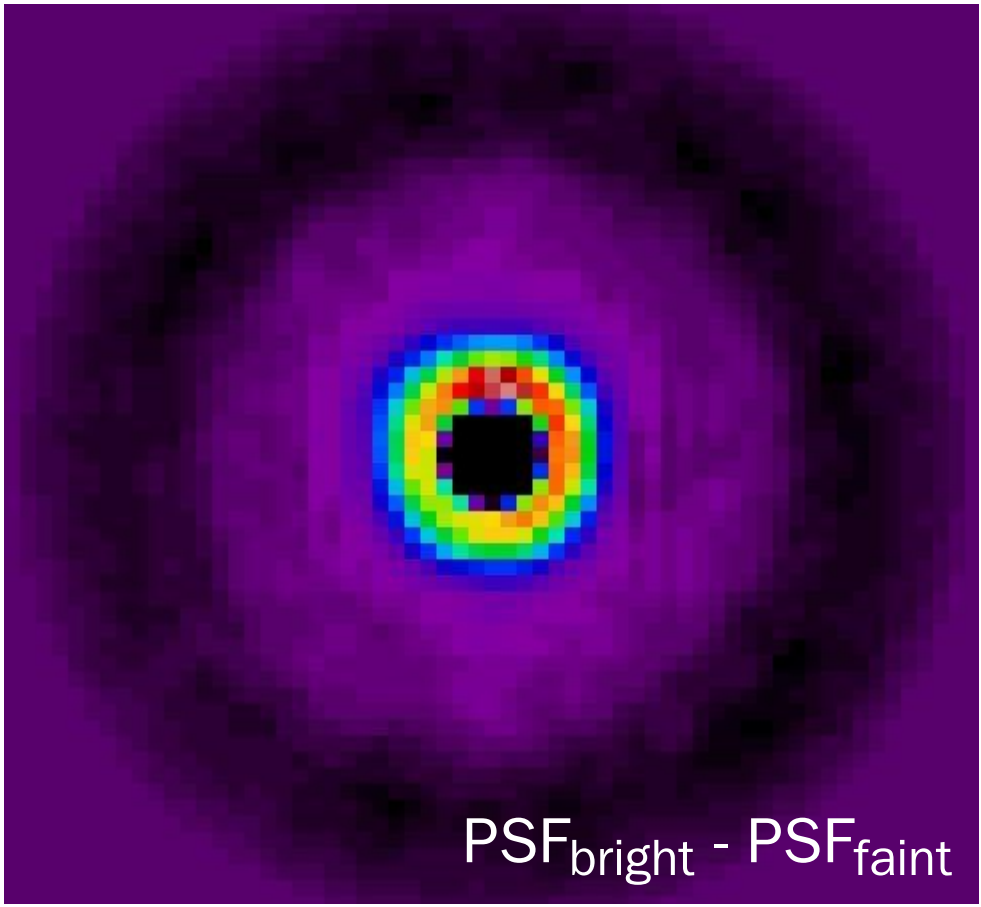
  astrometric pattern due to circularly symmetric gradient of resistance



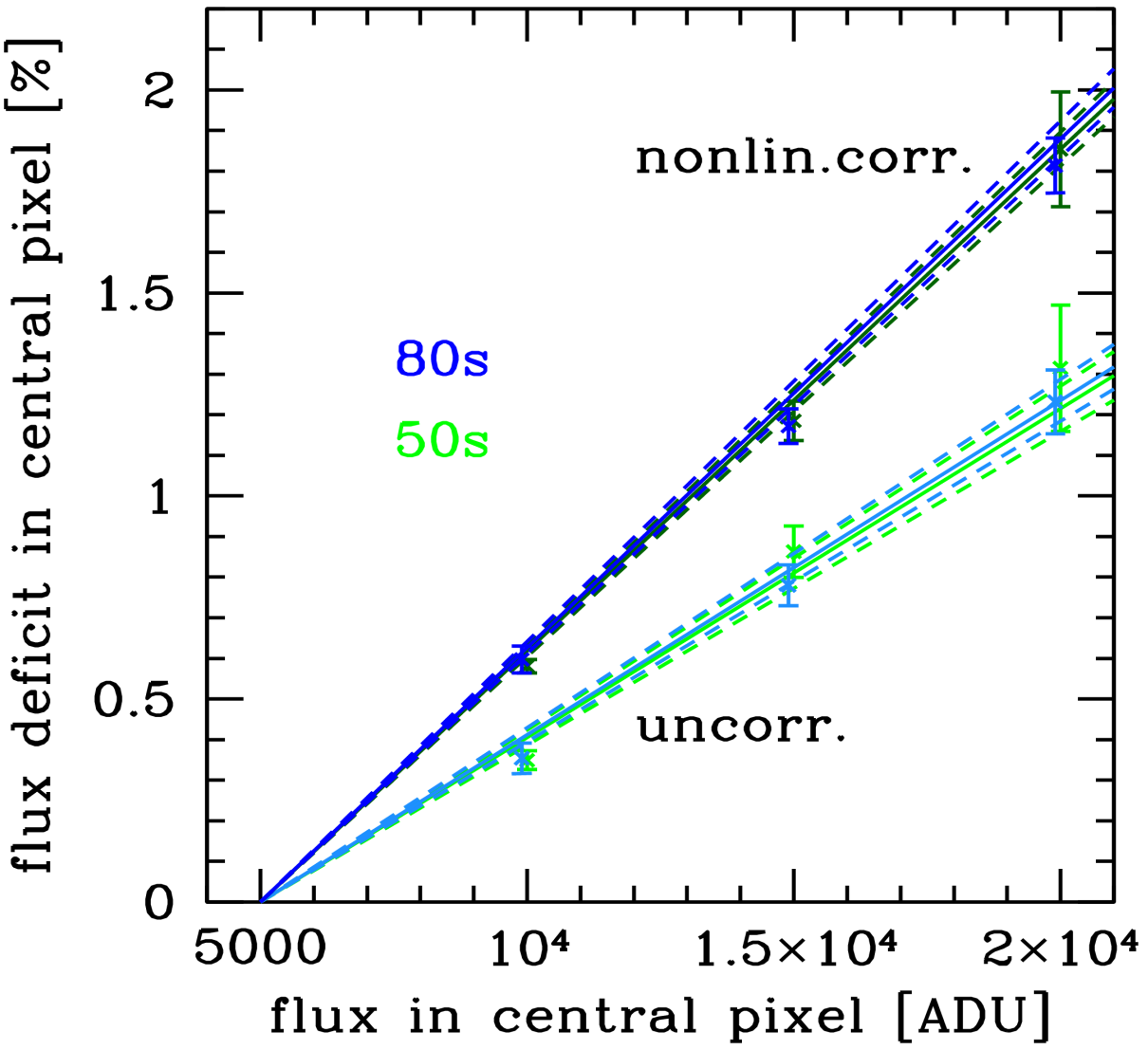
- Brighter/fatter effect

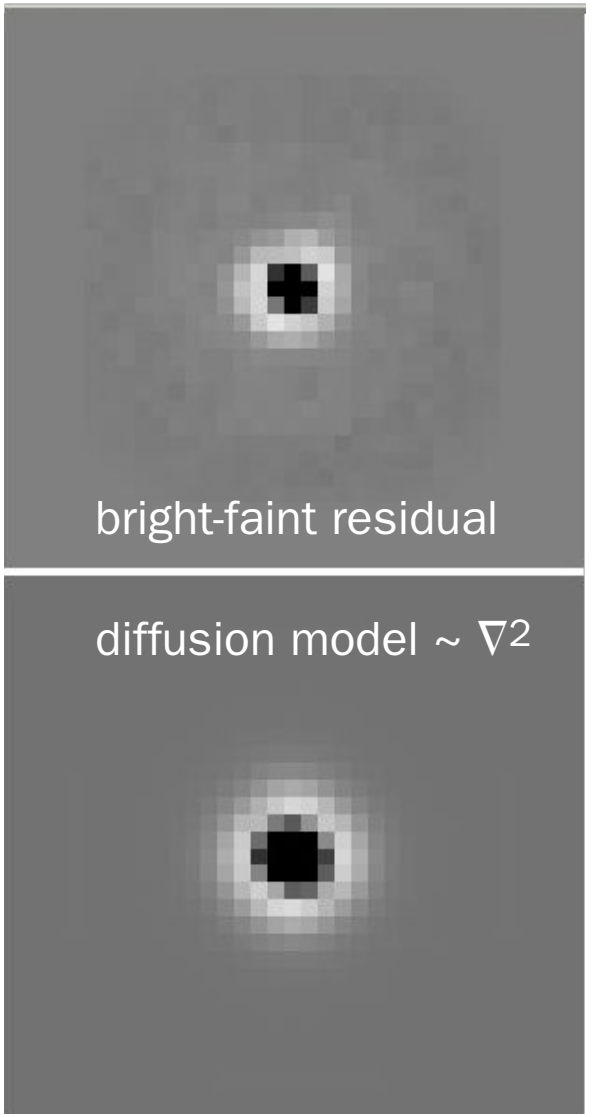
Brighter/fatter phenomenology:
PSF size increases isotropically with flux





It's linear in flux, it's not the flat nonlinearity, it's independent of t_{exp}, it's not (just) diffusion





Model introduction:

charge-induced shift of effective pixel borders

- Antilogus et al., PACCD 2013 arXiv:1402.0725

$$\delta_{ij}^{X} = \sum_{kl} a_{k-i,l-j}^{X} \times q_{kl}$$

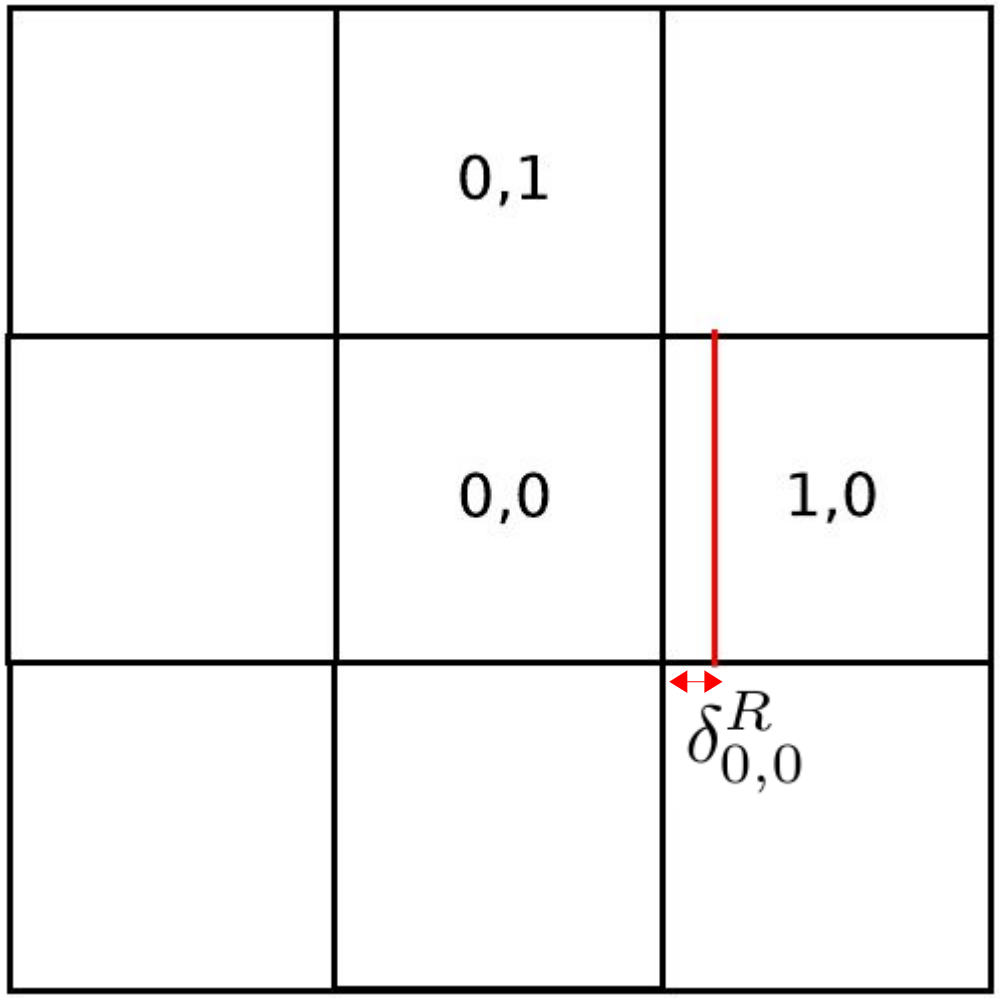
shift parameters

charge in pixel kl

- Change in flux:

$$\delta_{0,0}^{R} \times \frac{q_{0,0} + q_{1,0}}{2}$$

(plus other sides)

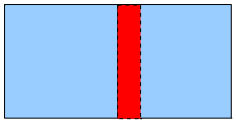


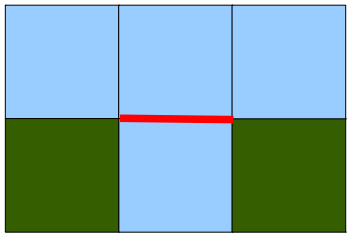
Model introduction:
symmetries reduce model parameters

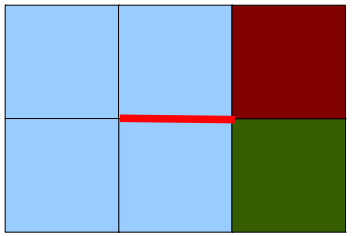
These are lots of parameters, but a priori we expect...

$$a^{L}_{ij} = -a^{R}_{i+1,j} \qquad a^{0,\pm1}_{i,j} = a^{0,\pm1}_{-i,j} \qquad a^{0,\pm1}_{i,j} = -a^{0,\pm1}_{i,\pm1-j}$$

$$a^{B}_{ij} = -a^{T}_{i,j+1} \qquad a^{\pm1,0}_{i,j} = a^{\pm1,0}_{i,-j} \qquad a^{\pm1,0}_{i,j} = -a^{\pm1,0}_{\pm1-i,j}$$





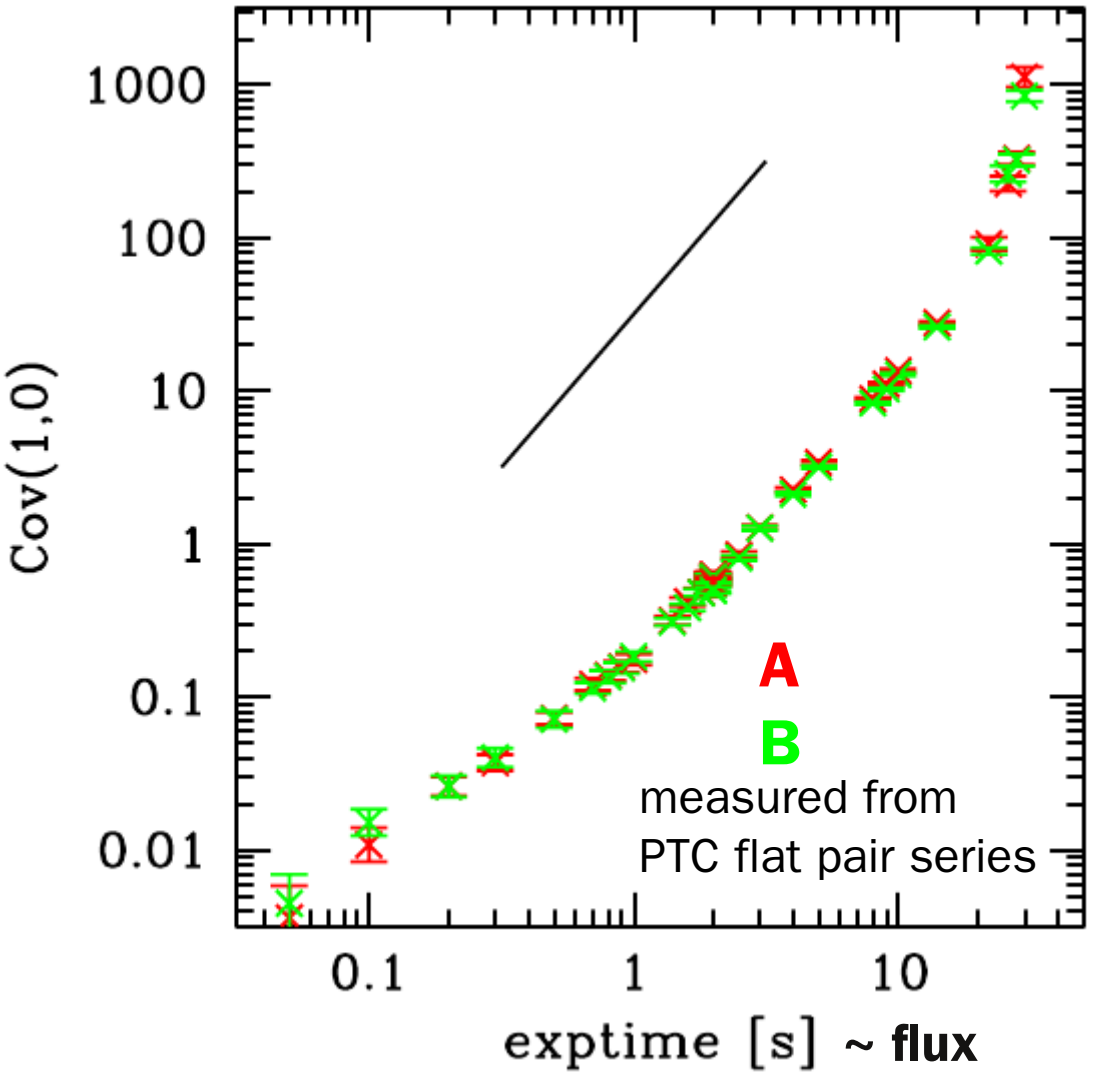


Model introduction:
connection to flat-field covariances

shift parameters are constrained by pixel-to-pixel covariances in flat field*

$$\mathrm{cov}(Q_{00}, Q_{ij}) = 2V\mu \sum_{X=T,B,L,R} a_{ij}^{X}$$

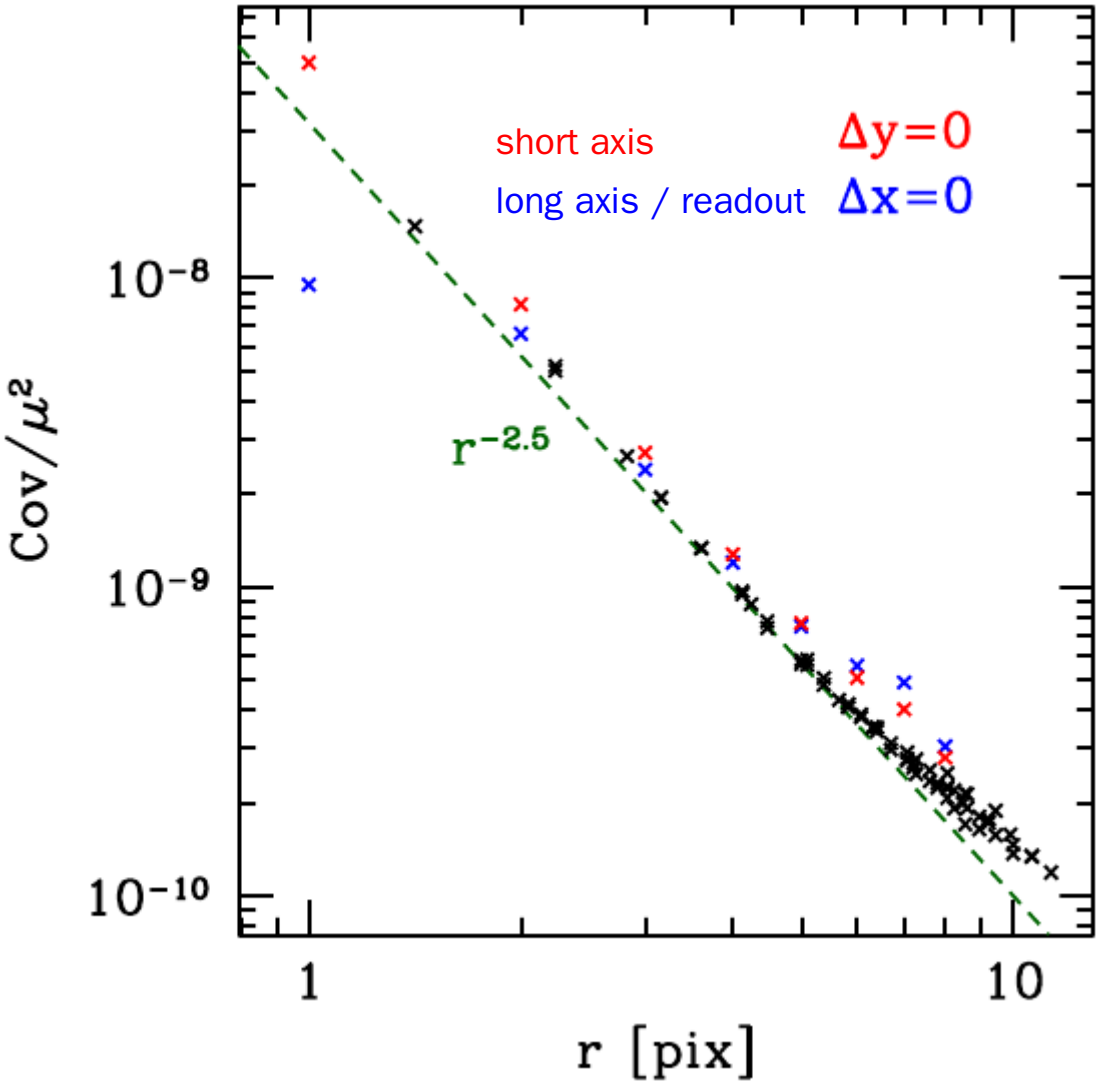
flux^2 dependence



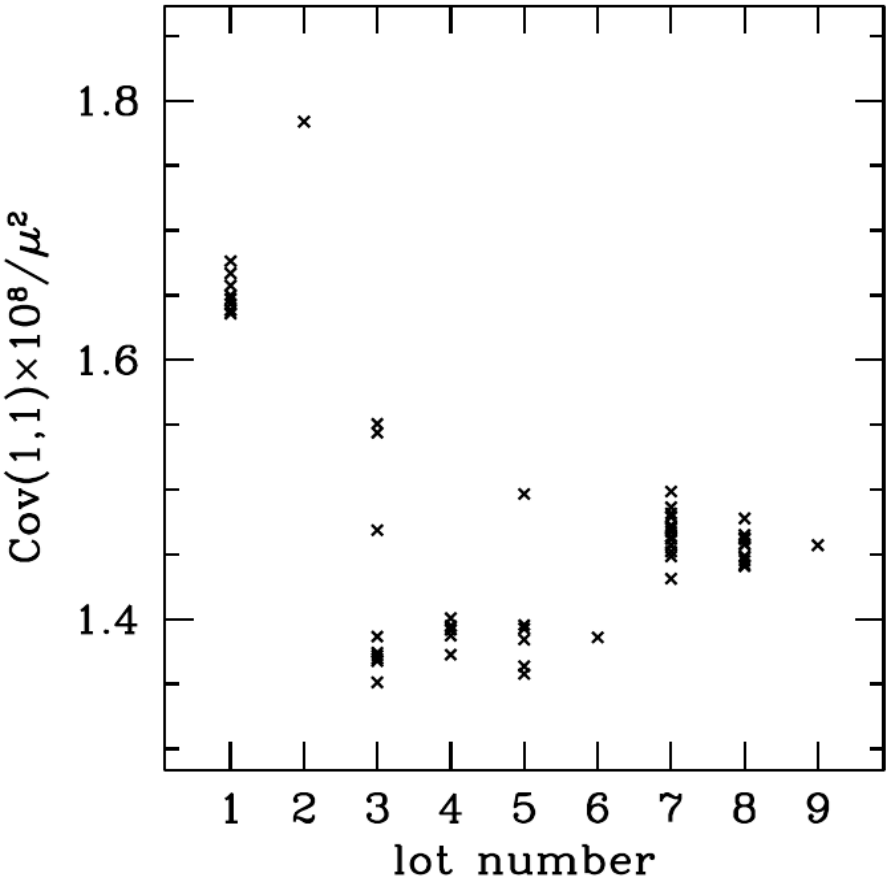
* with a few issues I'll talk about in a minute

DECam measurements:
flat field pixel-to-pixel covariances

- Data: full season of r band dome flats: 1200 frames, 6×10^{11}pix, $4 \times 10^{16}\gamma$
- Lots of consistenty checks
- Covariances with S/N~15 at r~10pix
- Power-law behaviour with different amplitude for on-axis pixels
- Outlier: neighbour along readout factor ~ 5 low



DECam measurements:
chip-to-chip variation

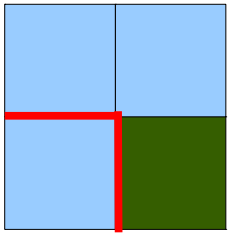


- Covariance levels differ by ~20% between different chips
- Levels correlate within CCD production lots
- Origin unknown

DECam model:
from covariances to shift coefficients

- Covariances do not uniquely constrain coefficients without further assumptions

$$
\begin{aligned}
a^R_{1,0} &\rightarrow a^R_{1,0} + \Delta \\
a^T_{0,1} &\rightarrow a^T_{0,1} - \Delta \\
a^R_{1,1} &\rightarrow a^R_{1,1} + \Delta/2 \\
a^T_{1,1} &\rightarrow a^T_{1,1} - \Delta/2
\end{aligned}
$$



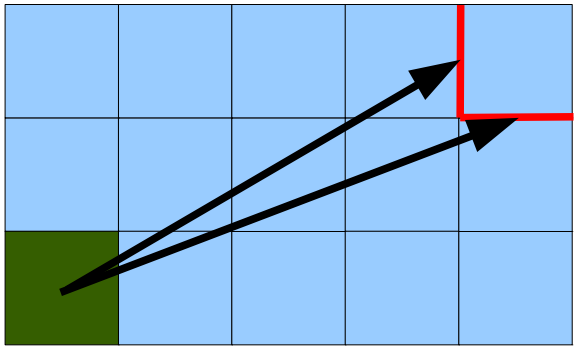
- We make these two:

$$a^R_{ij} = a^T_{ji}$$

for off-axis pixels >1 away

$$a^R_{j,i} = r(i,j)\, a^R_{i,j}$$

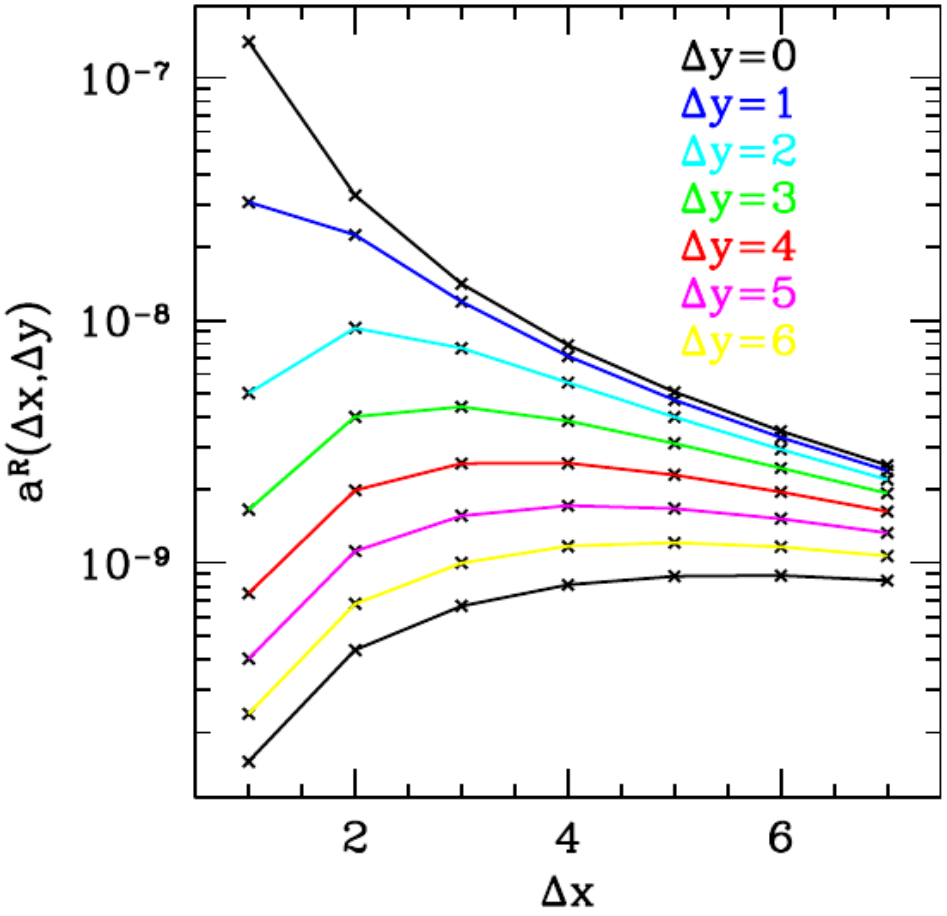
same force, corrected for projection

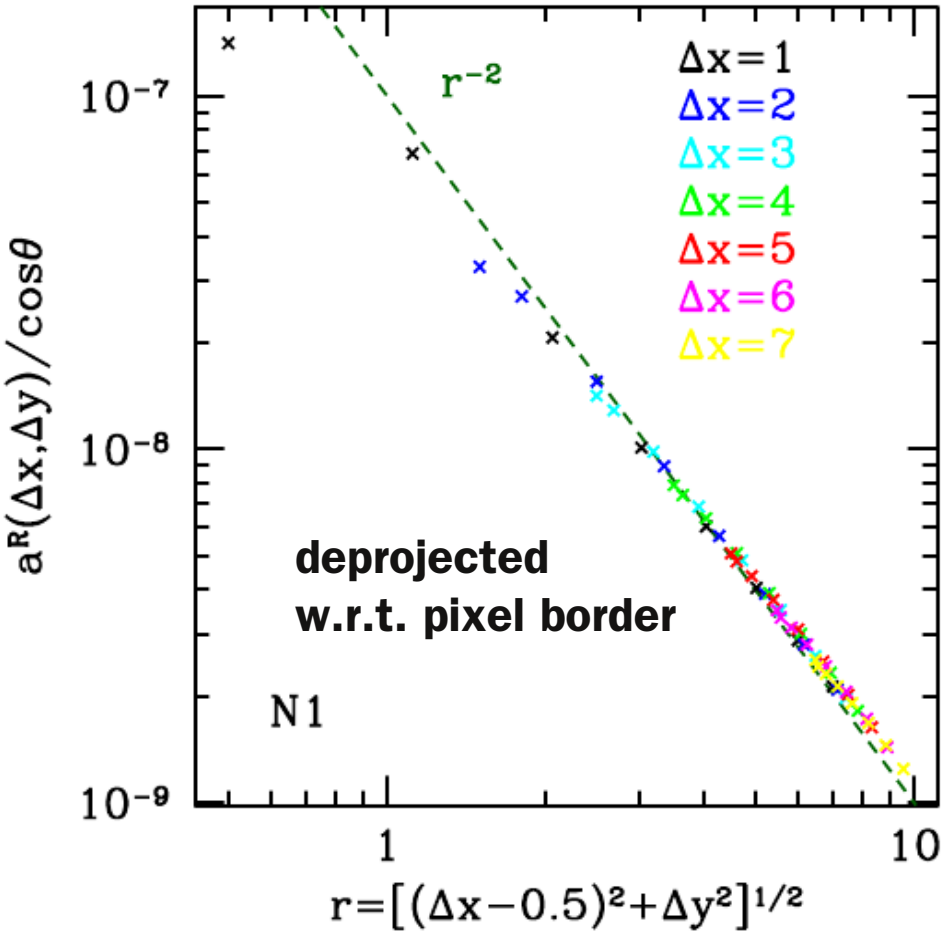


➔ Linear relation of a and Cov

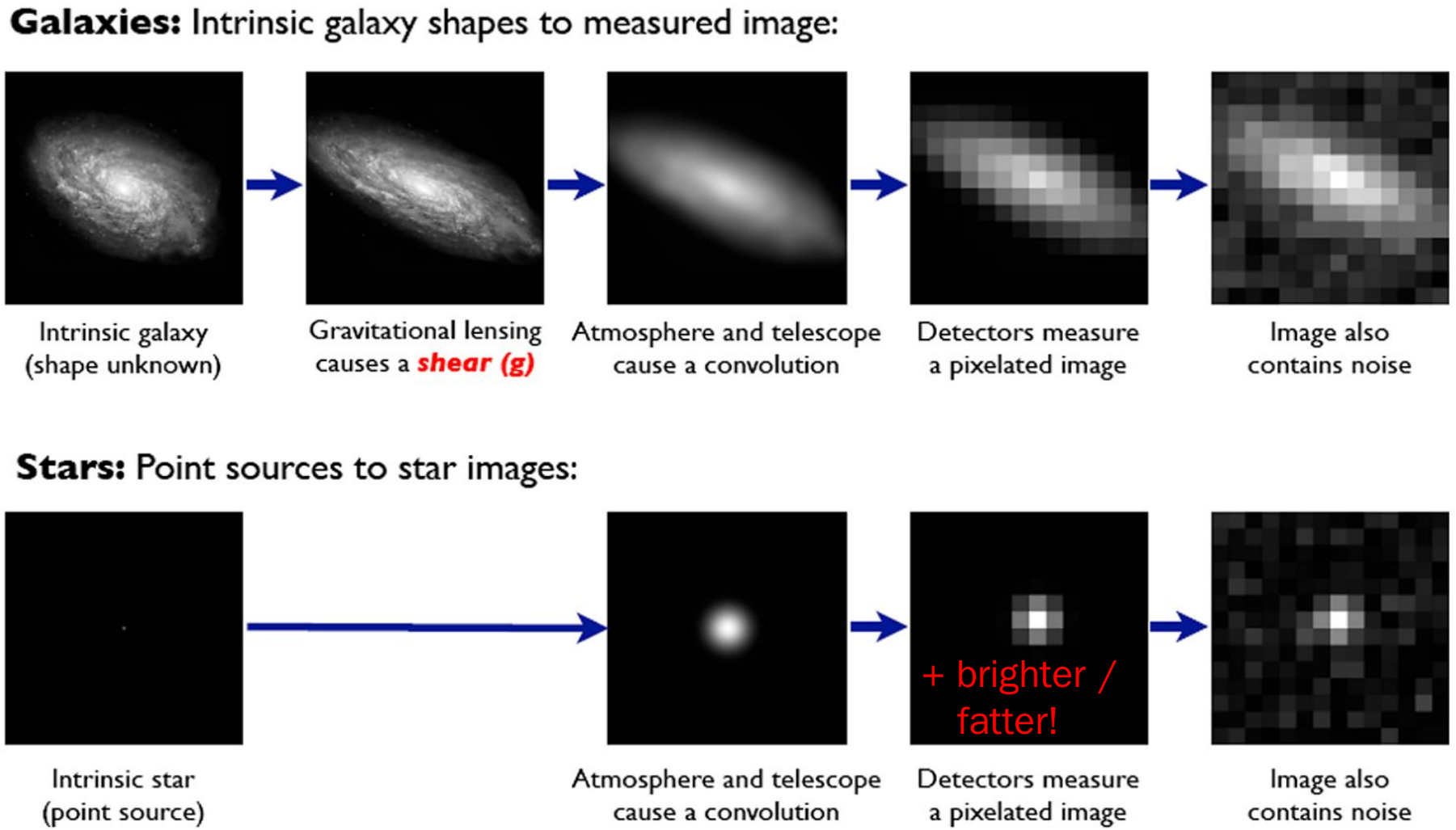
- directly measured covariances + power-law extrapolation

DECam model:
shift coefficients of individual chips





Effect on galaxy shape measurement:



Source: Bridle et al. 2009

Effect on galaxy shape measurement: Image simulation with GalSim

- Implementation of Antilogus+2014 model in CDModel module of GalSim (Rowe+2014)

  `https://github.com/GalSim-developers/GalSim/`

- simulations with mean DECam model and
  - star images with 15k ADU peak flux as PSF model
  - faint galaxies with no background / no noise
  - seeing FWHM 0.9'', intrinsic galaxy FWHM 0.5''

$$\begin{pmatrix} \epsilon_1^{\rm meas} - \epsilon_1^{\rm true} \\ \epsilon_2^{\rm meas} - \epsilon_2^{\rm true} \end{pmatrix} = \begin{pmatrix} m_1 \epsilon_1^{\rm true} + c_1 \\ m_2 \epsilon_2^{\rm true} + c_2 \end{pmatrix} + \begin{pmatrix} p_1^1 \epsilon_1^p \\ p_2^2 \epsilon_2^p \end{pmatrix}$$

multiplicative bias

additive bias

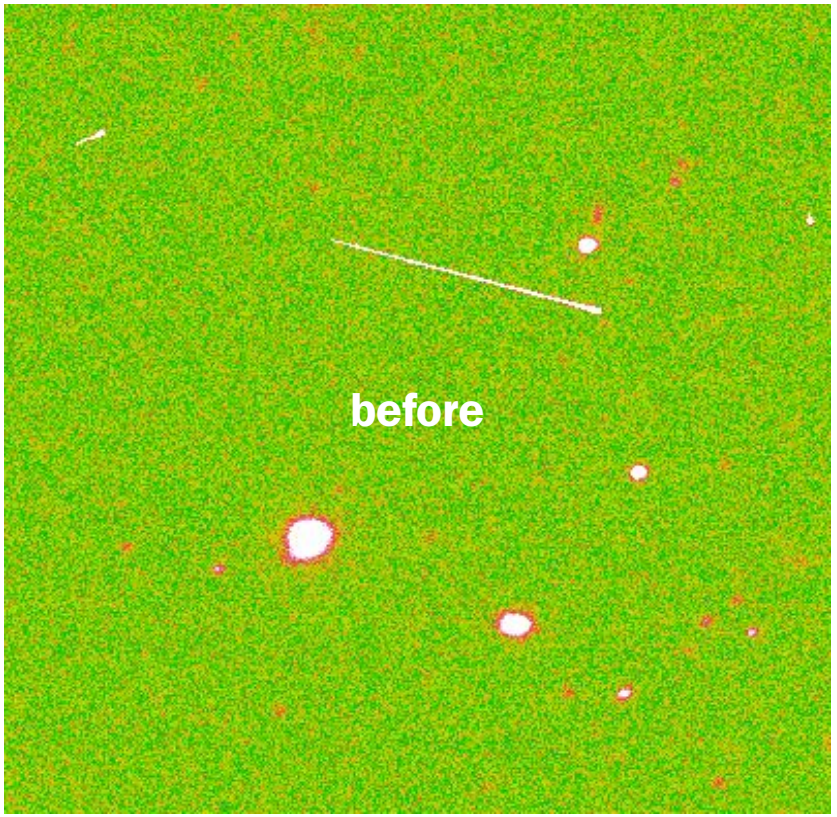
PSF leakage

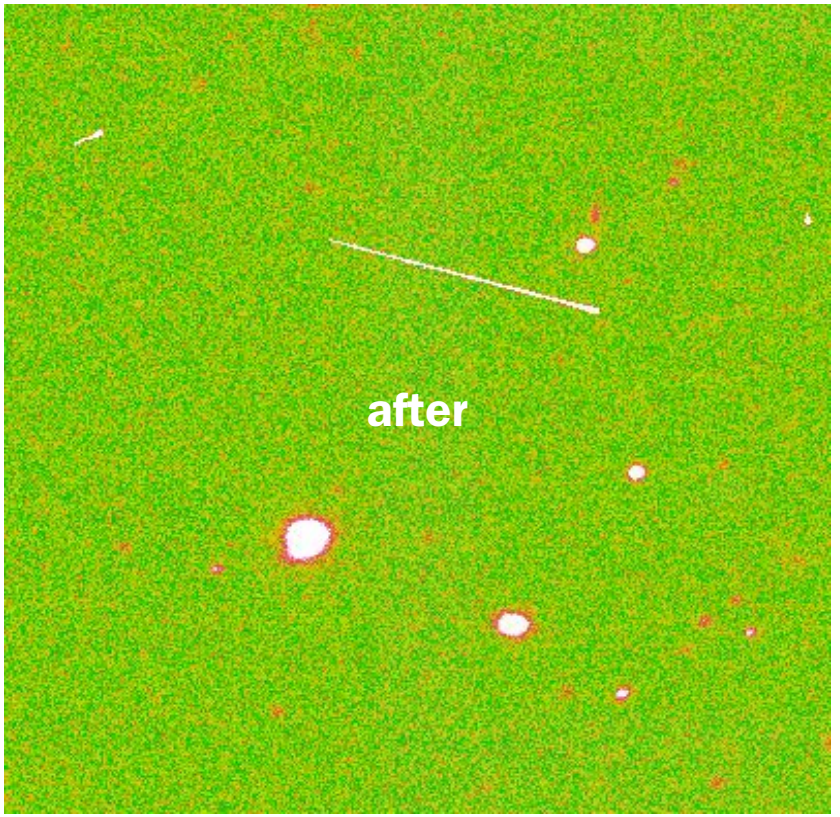
Effect on galaxy shape measurement: multiplicative shape bias

settings	$m[10^{-2}]$	$c_1[10^{-3}]$	$p_1^1[10^{-2}]$	$p_2^2[10^{-2}]$
fiducial	2.4	-0.5	-0.6	-0.7
$\mathrm{FHWM_{PSF}} = 0.7''$	1.7	-0.5	-0.4	-0.5
$\mathrm{FHWM_{PSF}} = 1.1''$	3.1	-0.5	-0.8	-0.9
$\mathrm{FHWM_{gal}} = 0.3''$	6.9	-1.4	-1.7	-2.0
$\mathrm{FHWM_{gal}} = 0.7''$	1.1	-0.3	-0.3	-0.3
500 ADU background	2.2	-0.5	-0.6	-0.7
symmetric $a_{ij}^T := a_{ji}^R$	2.5	0.0	-0.6	-0.7
corrected out to $\Delta = 5$	0.0	0.0	0.0	0.0
Systematic error budget (DES)	0.4	0.4		

- Primary effect is a multiplicative bias that exceeds DES requirements

Solution: pixel level correction





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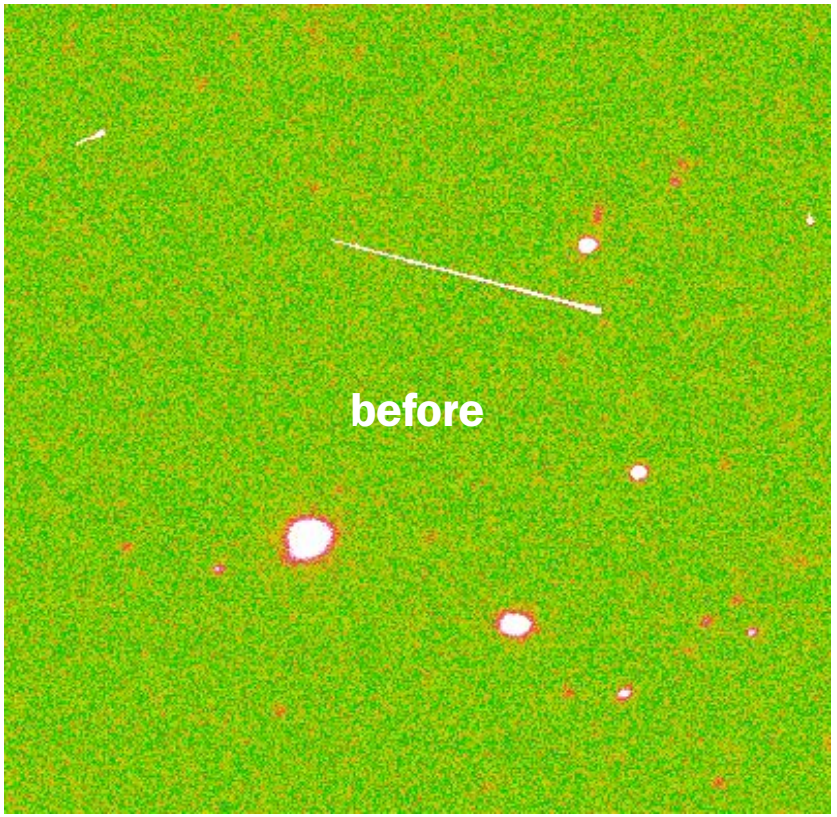

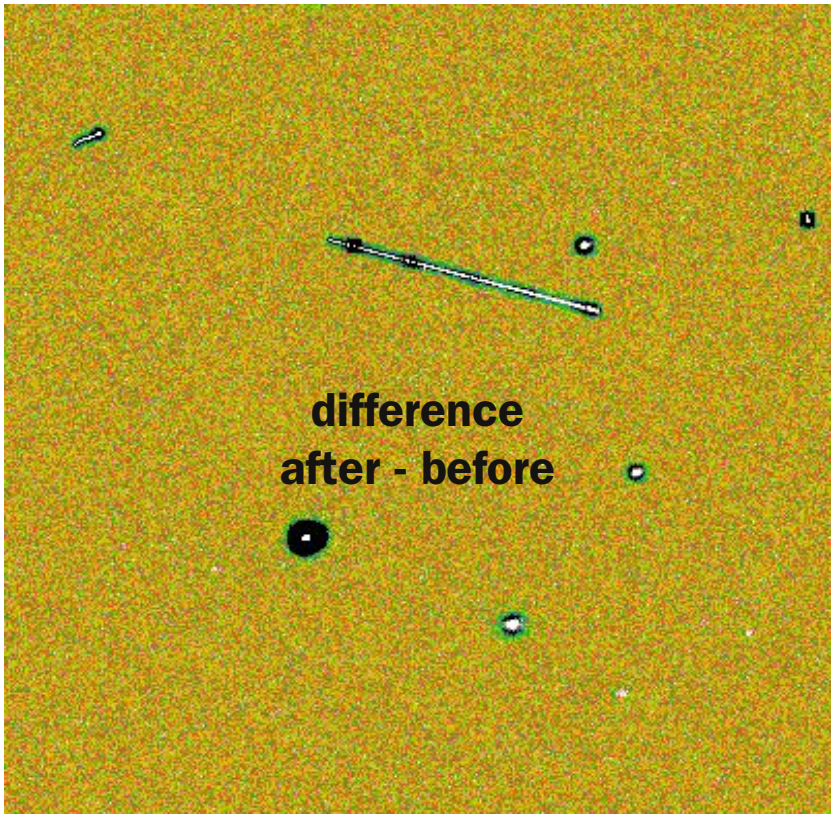

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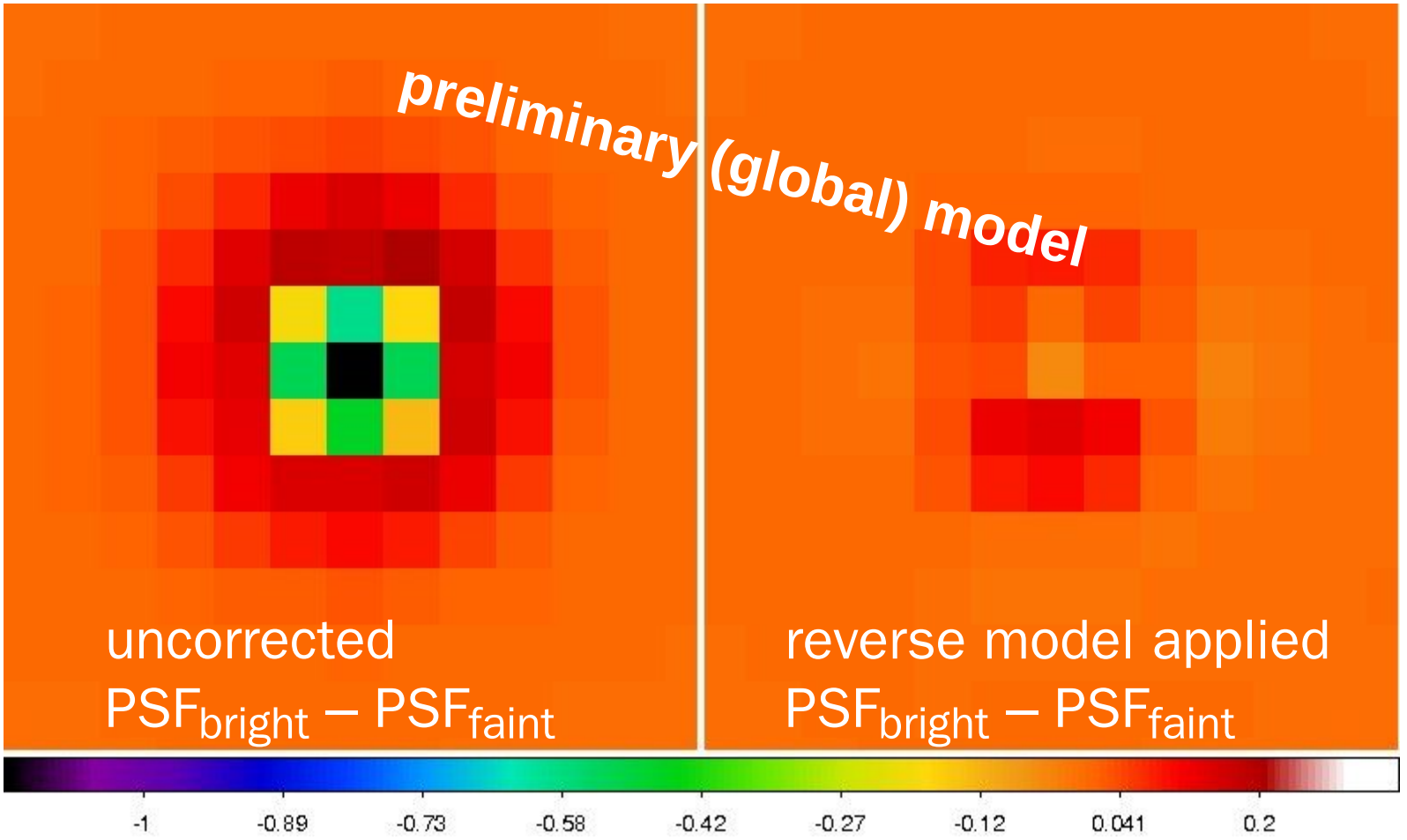


$$\Sigma(\mathrm{residual,corrected})^2/\Sigma(\mathrm{residual,uncorrected})^2 = 0.045$$

Summary

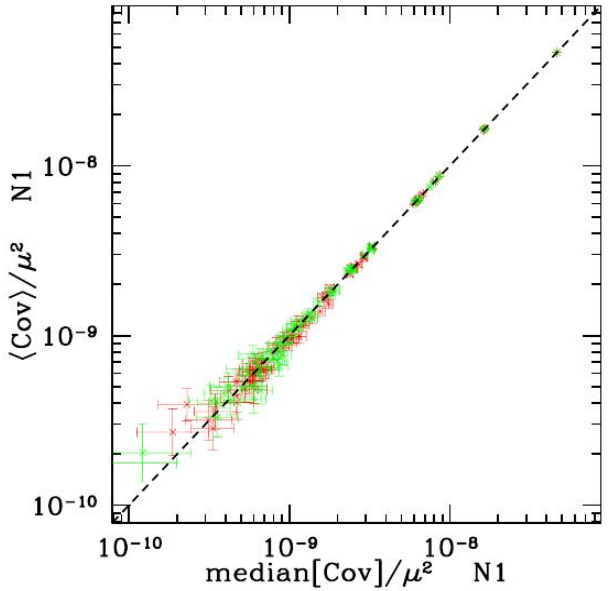
Charge self-interaction in DECam causes per-cent level systematics in weak lensing

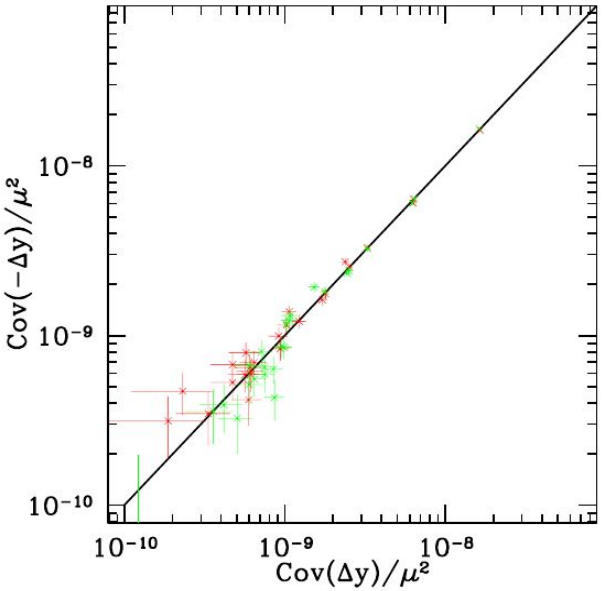
Characterization and correction of effect

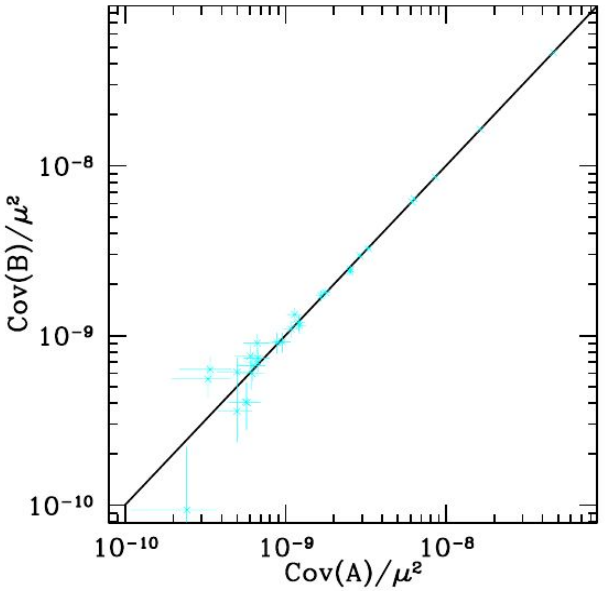
- using Antilogus+2014 model
- measurements on full season of flat data
- model fit per CCD
- pixel-level correction

Backup

DECam measurements: consistency checks







Covariance measurements consistent between

- mean and median
- rotated lags
- amplifiers / halves of chips
- months of the DES season